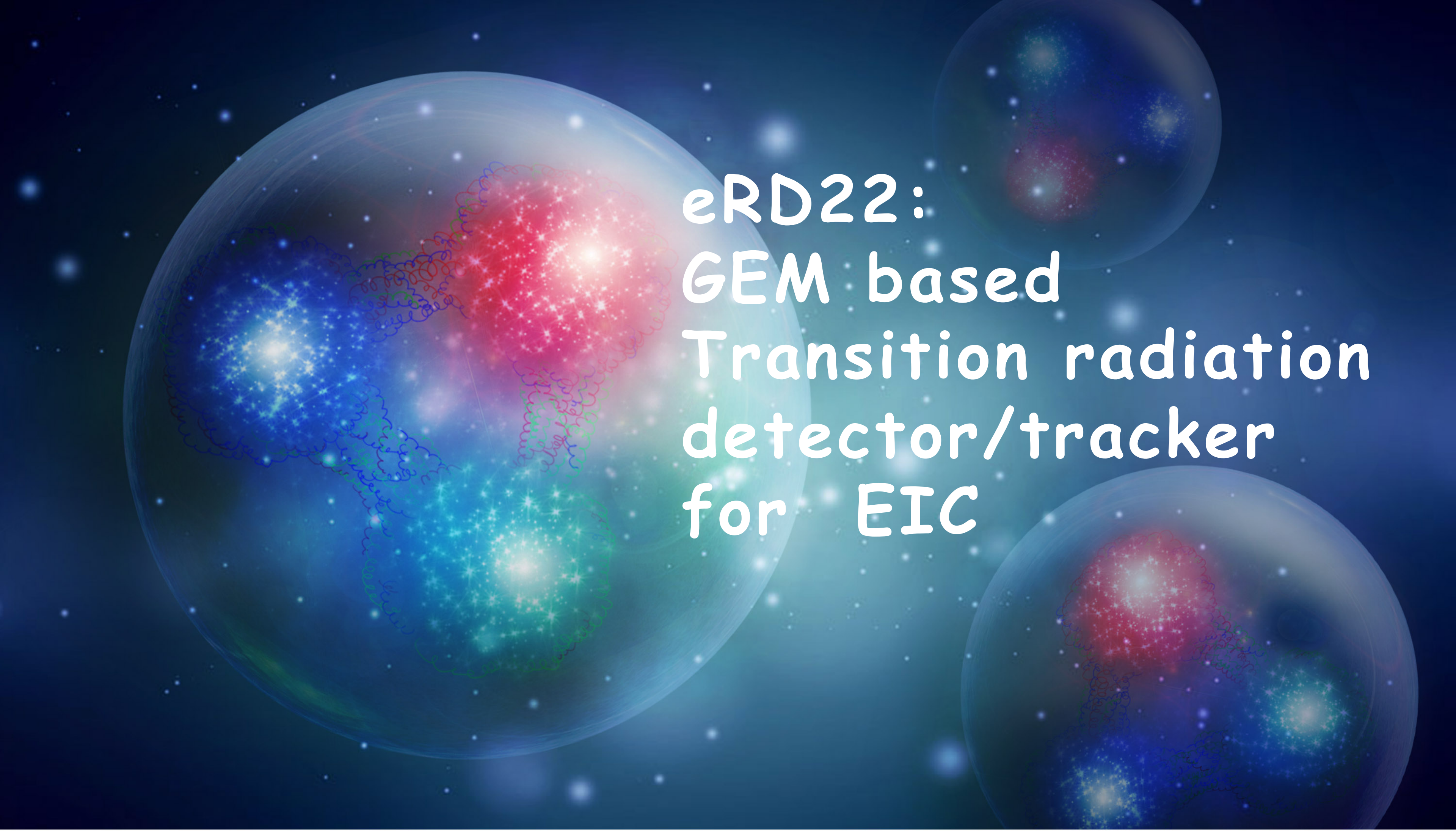
eRD22: GEM based Transition radiation detector/tracker for EIC



Yulia Furletova (JLAB) on behalf of GEM-TRD/T working group

January 2020

GEM-TRD/T TEAM:

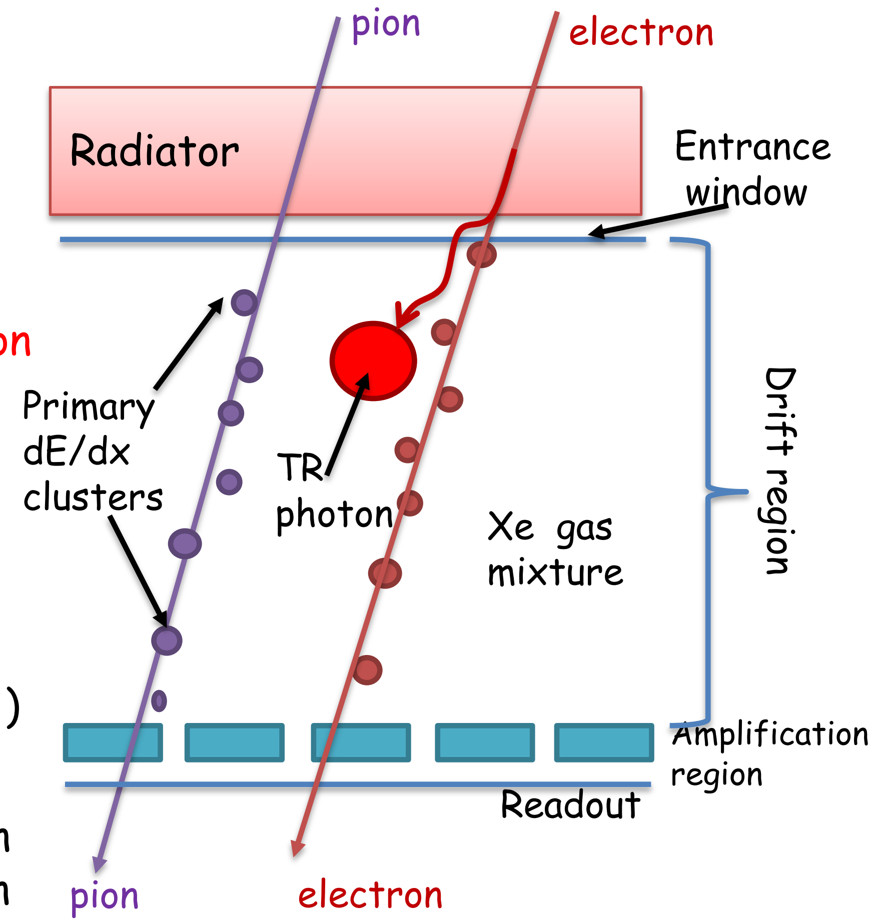
- Jefferson Lab:
  - ✓ Howard Fenker
  - ✓ Yulia Furletova
  - ✓ Sergey Furletov
  - ✓ Lubomir Pentchev
  - ✓ Beni Zihlmann
  - ✓ Chris Stanislav
  - ✓ Fernando Barbosa

- University of Virginia
  - ✓ Kondo Gnanvo
  - ✓ Nilanga K. Liyanage

- Temple University
  - ✓ Matt Posik
  - ✓ Bernd Surrow

GEM as Transition Radiation detector and tracker for EIC

- High resolution tracker.
- Low material budget detector
- How to convert GEM tracker to TRD:
  - ✓ Change gas mixture from Argon to Xenon (TRD uses a heavy gas for efficient absorption of X-rays)
  - ✓ Increase drift region up to 2-3 cm (for the same reason).
  - ✓ Add a radiator in the front of each chamber (radiator thickness ~5-20cm)
  - ✓ Number of layers depends on needs: Single layer could provide e/pi rejection at level of 10 with a reasonable electron efficiency.



Was planned to do within FY20:

- ❑ Joint test with DIRC detector (integrated to GlueX framework) for pion run.
- ❑ Test gas mixing system.
- ❑ Test gas-mixture for contaminations.
- ❑ Continue Geant4 development
- ❑ Collaboration with tracking and streaming readout consortia
- ❑ Publication (?)

Electron hadron rejection

To measure a real e/π rejection factor we need a pion beam!!!
(Fermilab, CERN testbeams have both e and hadron beams)

Problem: we do not have our own readout electronics (borrowed from JLAB Hall-D)

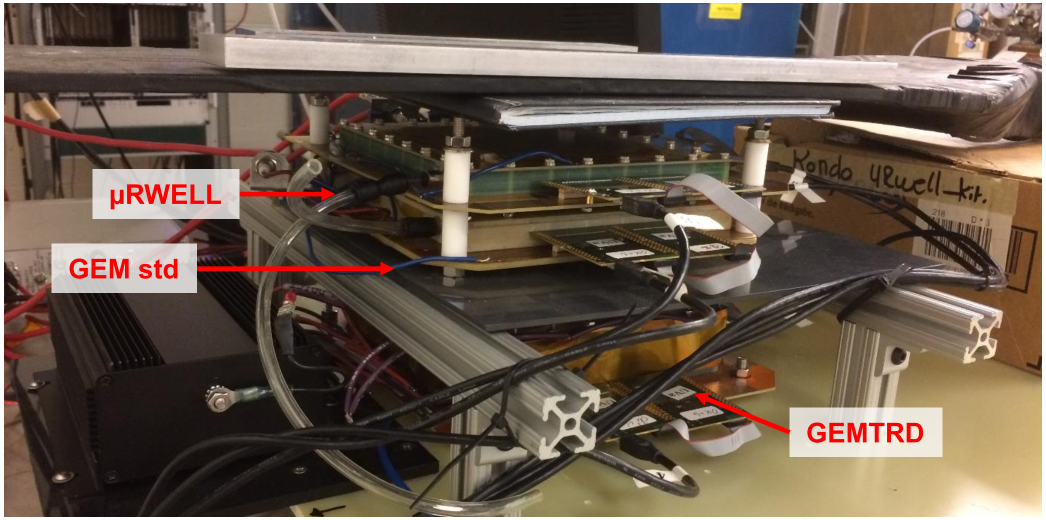
Solution (1) : use pions from $\rho - meson$ decays (real GlueX physics !)
Use a commissioning run in December for DIRC at Glue-X for 2 weeks.
Our proposal is

- to install GEM-TRD setup in front or behind DIRC detector (new mechanical support)
- Integrate GEM-TRD into GlueX Data-acquisition data processing,
- Integrate GEM-TRD into post-processing (analysis)

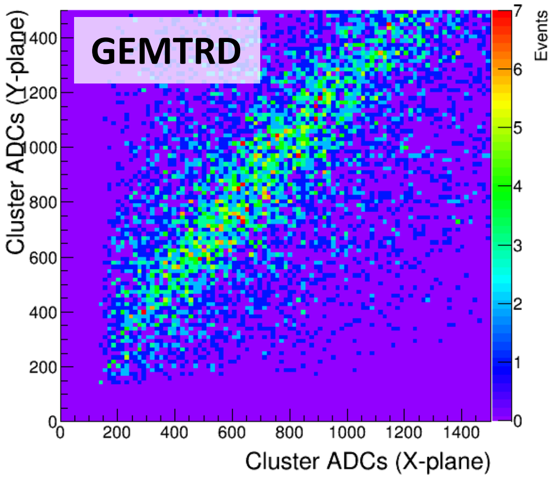
Solution (2): use Fermilab or CERN testbeam, need a financial support for R/O.
Also:
Have a joint test-beam with EMCAL (eRD1) to estimate a Global PID (e/π) performance

UVA cosmic test

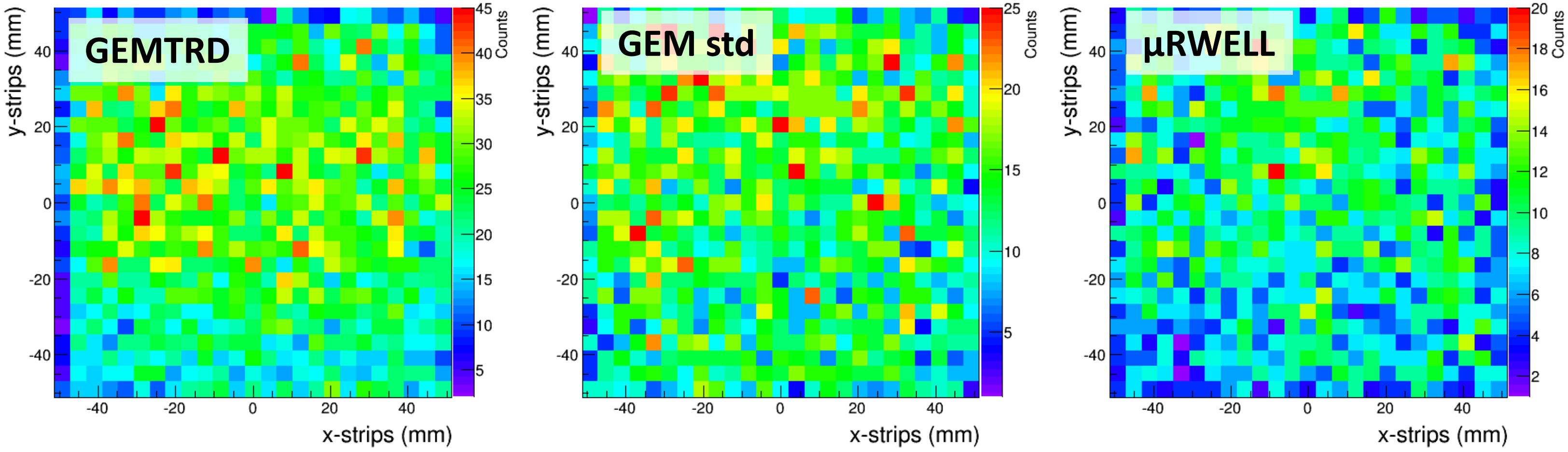
GEMTRD Test in cosmic setup @ UVa



X-Y charge sharing

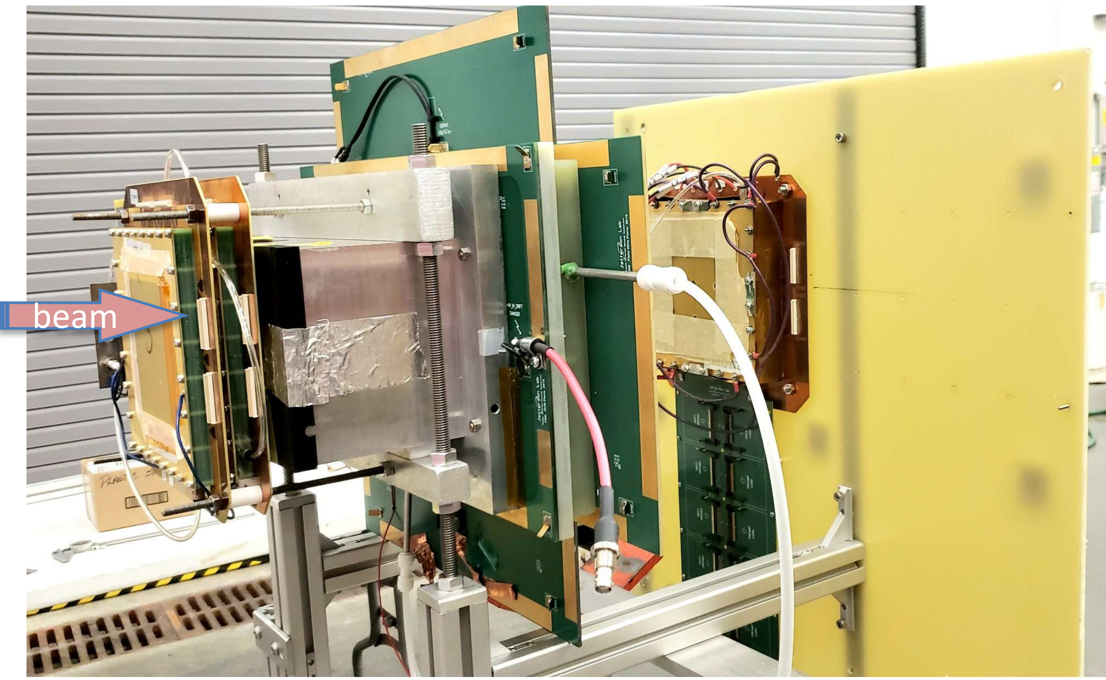


Reconstructed position hit map



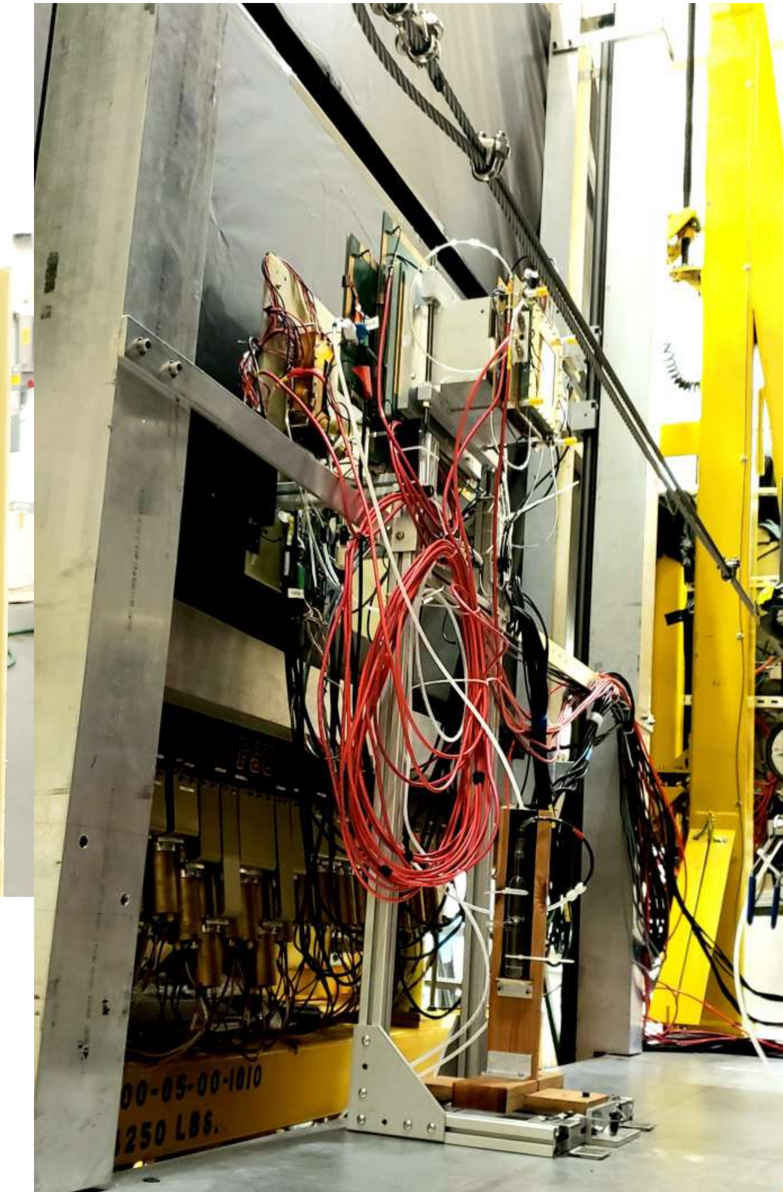
GEMTRD test setup with GlueX

- <u>Motivation:</u>
- To check for real e/pi rejection (detector response on pions)
- Also important for DIRC (precise tracking in front of the detector)



- Setup: 5 tracking detectors

Counting from the target:
-Standard GEM, uRWELL, TRD Multi wire chamber (TRD-MW), GEM-TRD, Standard GEM plane.



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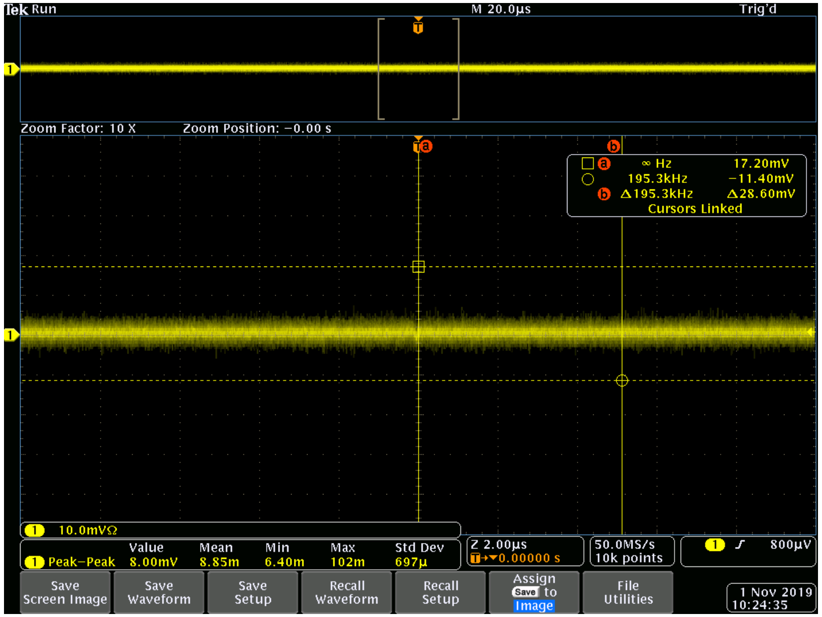
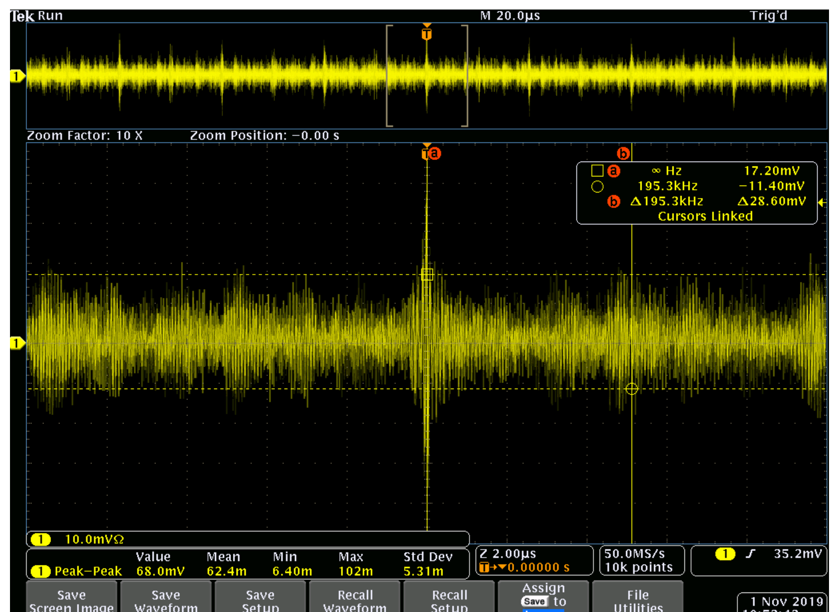
Noise test





a) electronics alone with two carrier PCBs, each with 10 preamps, all powered (480 channels): noise 9 mVpp (as previously in the lab) .

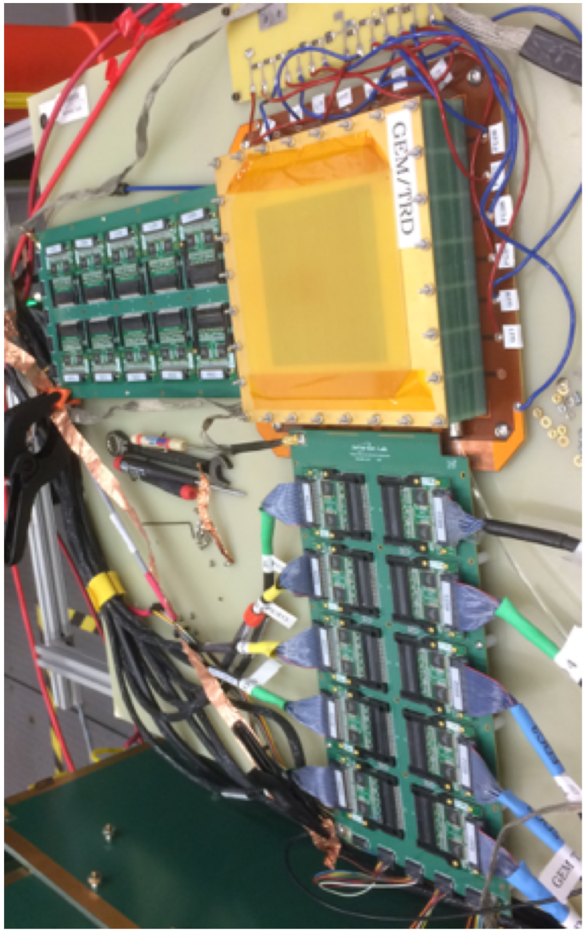
b) one of the carrier boards attached to the detector X coordinate : noise 11 mVpp.

c) two carrier boards attached to the detector X and Y coordinates: The noise increased considerably to 61 mVpp.

Noise and Fe55 test

=> These show that there is coupling on the detector between the X and Y strips. The long strips on the carrier boards, though shielded, may act as antennas

Since the time for installation was very limited, we decided to disconnect the Y coordinate. Fe55 test on X-strips was good!



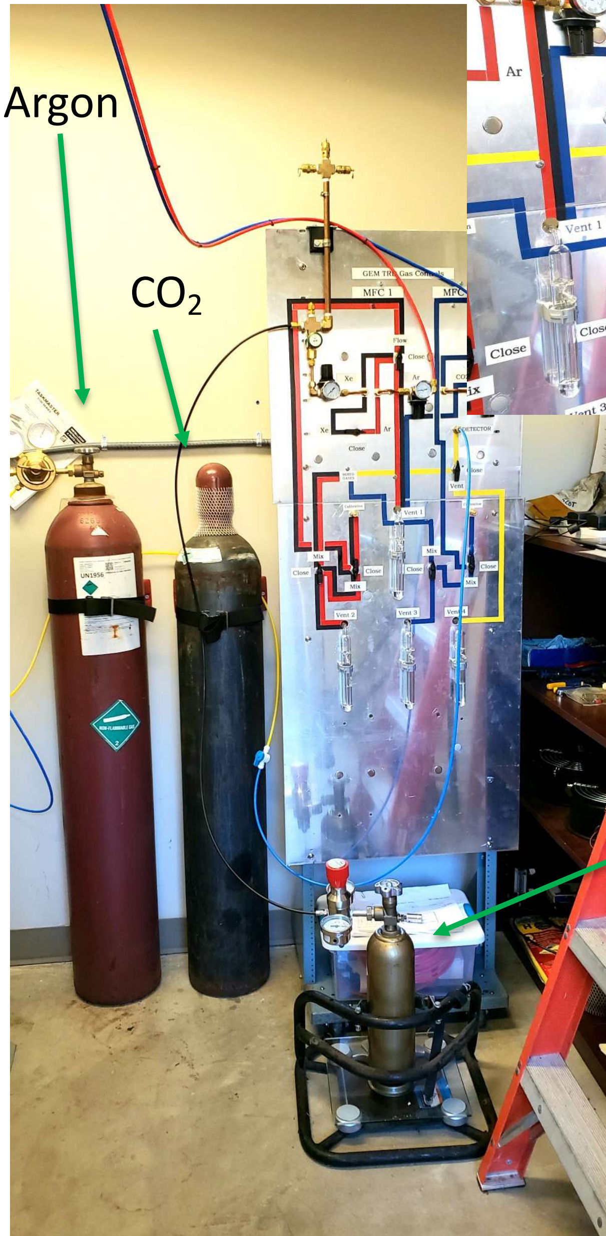
Gas system

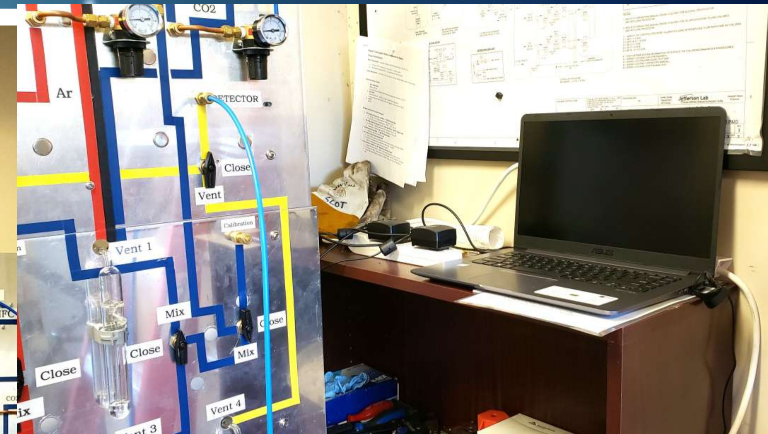
- Without a re-circulation and a purification system (too early stage of R&D)
- Gas mixing system
- Flow controller, CO_2 controller

➢ Assembled at Temple U.

➢ Delivered to JLAB (hall-D) in Jan 2019

➢ Approved for a safety and operation under pressure in September



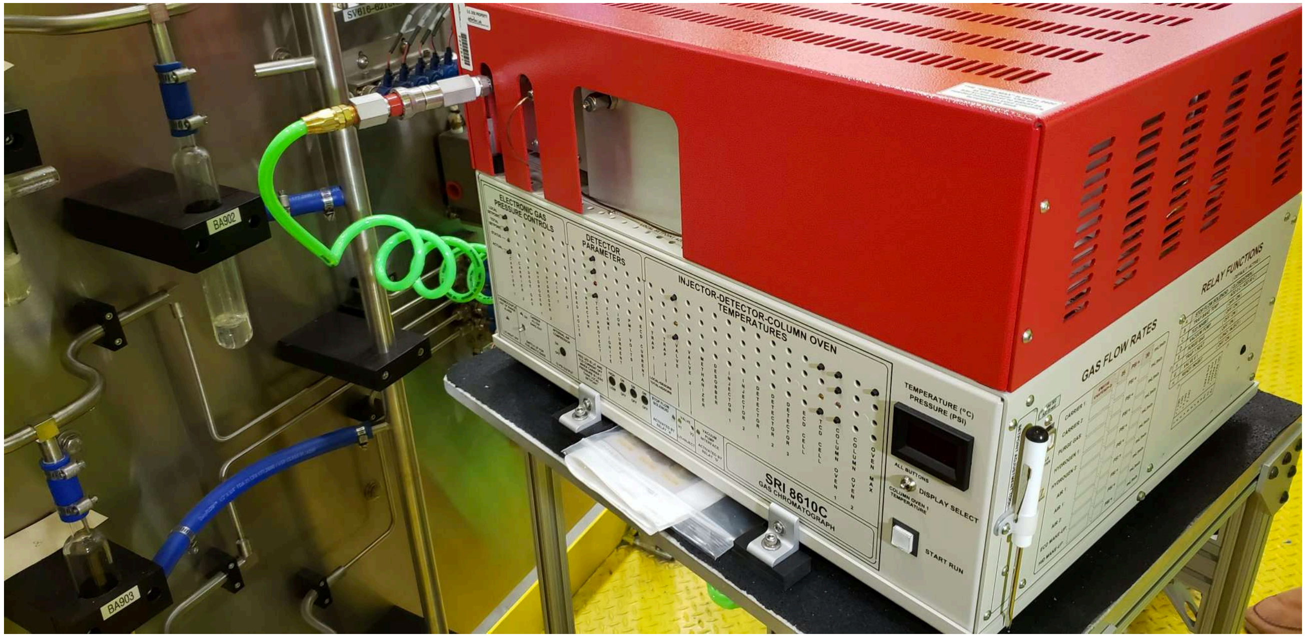


Gas mixing setup:
Xenon/CO2: 80/20 percent.

Gas quality monitoring system

We purchased gas chromatograph to begin quantifying and monitoring contaminations and to measure the concentrations of the Xe and CO_2 gasses.

-> split a cost with Hall-D : our contribution $7k (40%) to extend up to Xe



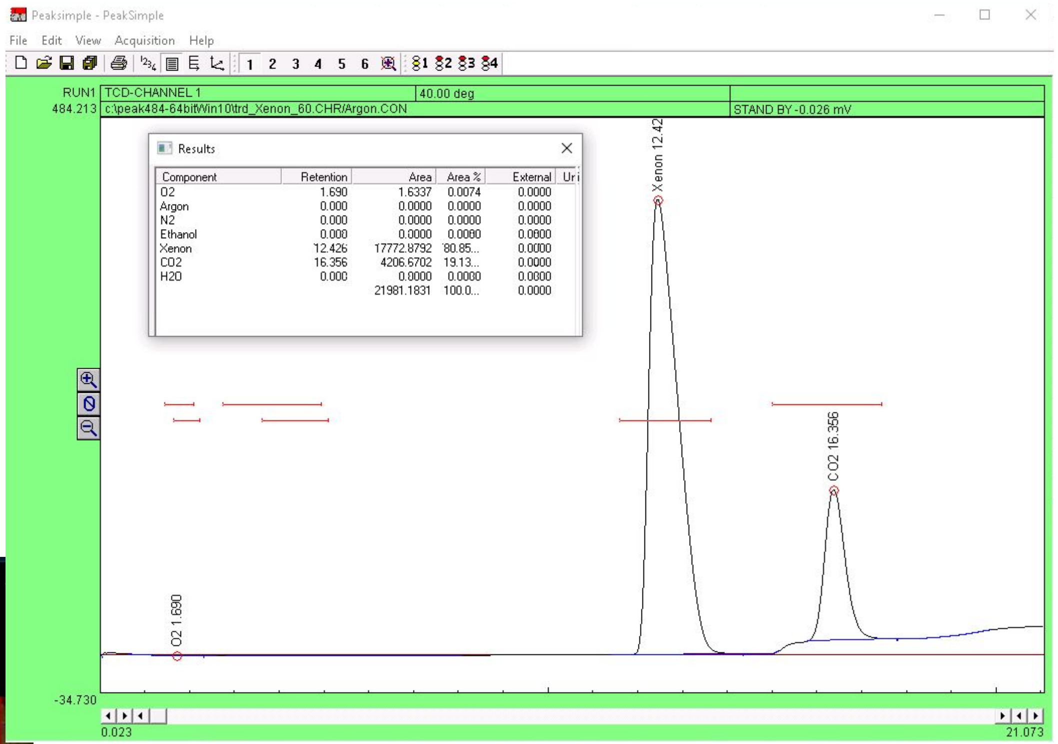
SRI 8610C

Helium gas as carrier

Yulia Furletova

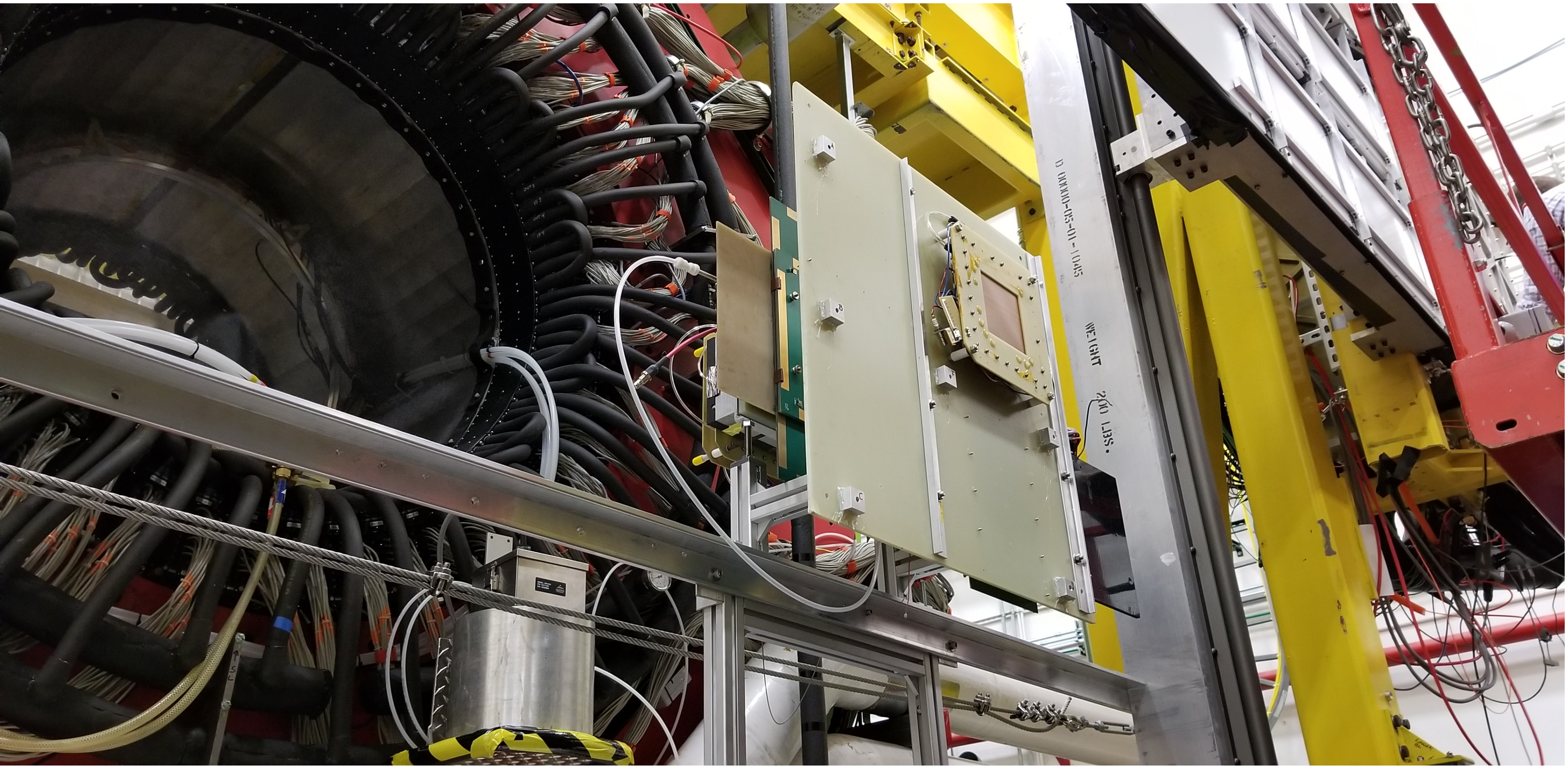
Gas quality monitoring system

- Remote access and measurements

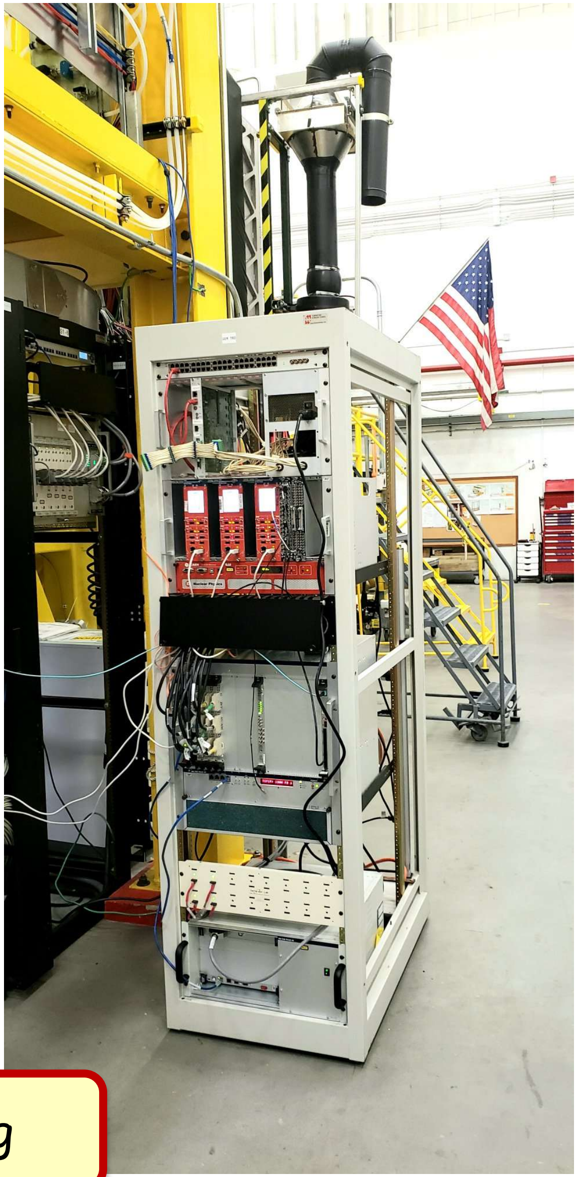


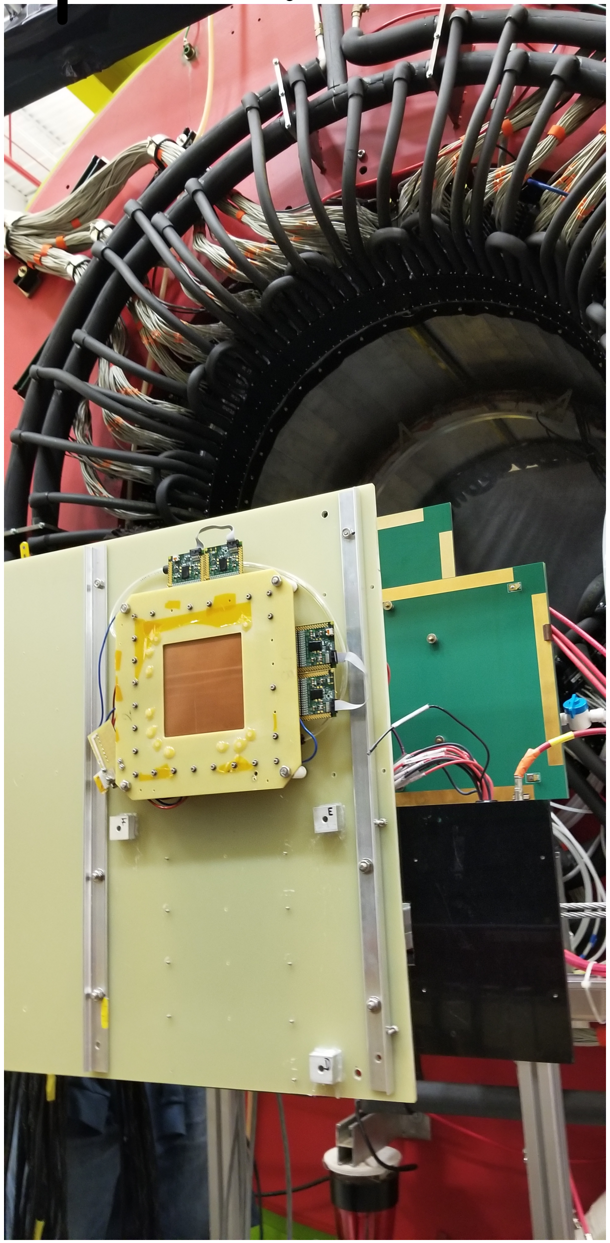
Measured Xe/CO2 : 80.85 and 19.15 percent.

GEMTRD setup at the GlueX experiment



Integration into GlueX experiment

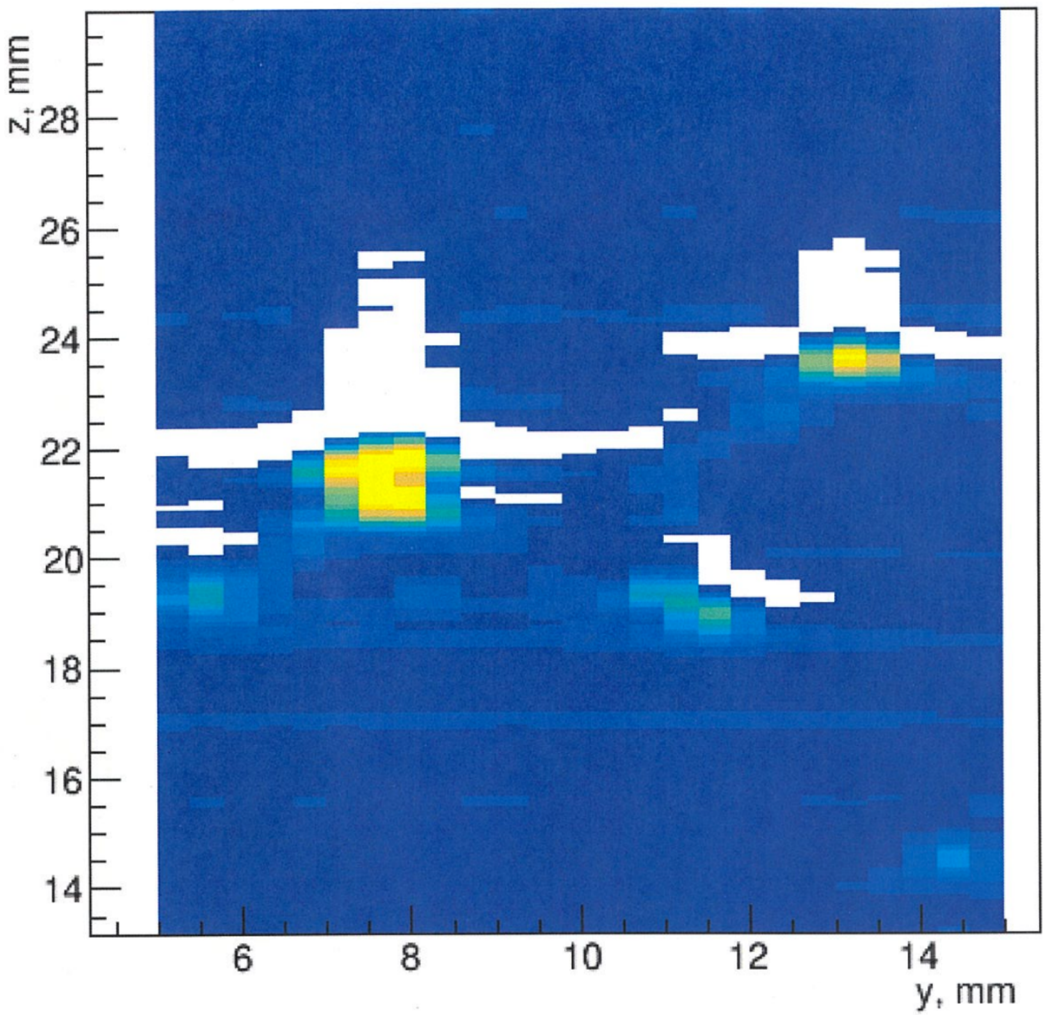




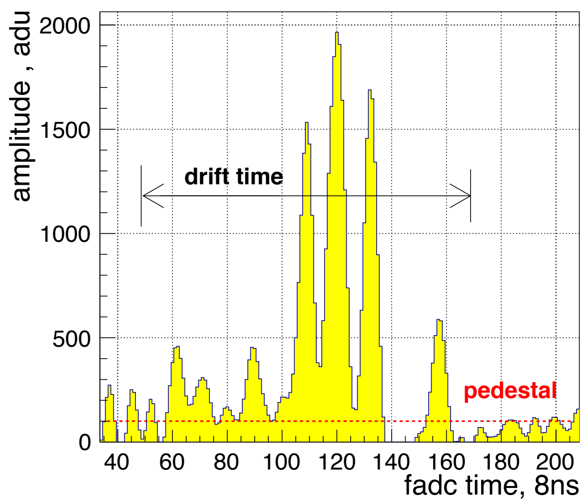
Data analysis are ongoing

Readout electronics: undershooting

GEMTRD



saturation of pre-amps. For the next test beam we are going to reduce the amplification value of pre-ampls (and maybe need to reduce GEM amplification)

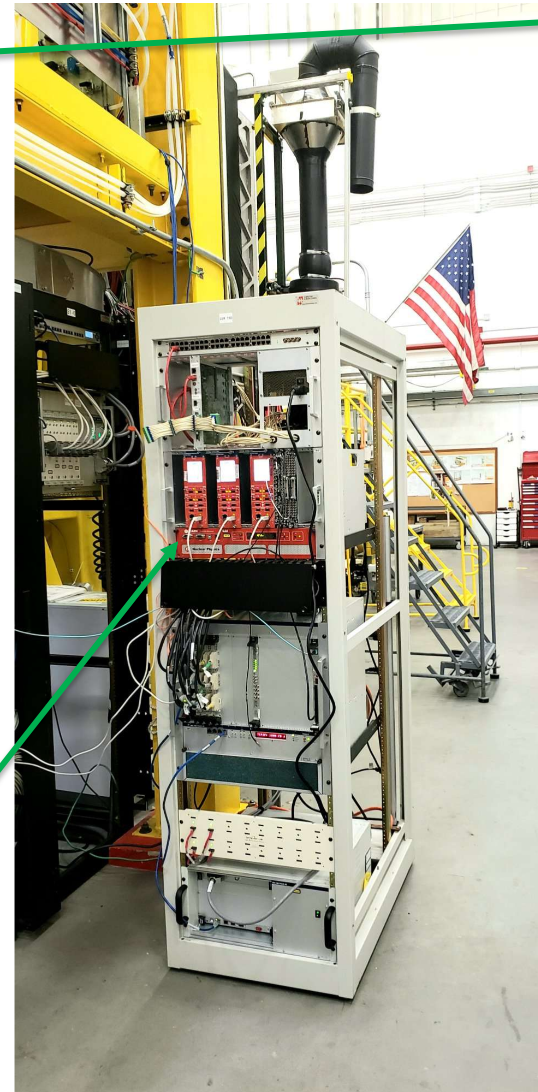


Problems with a HV crate during the spring run

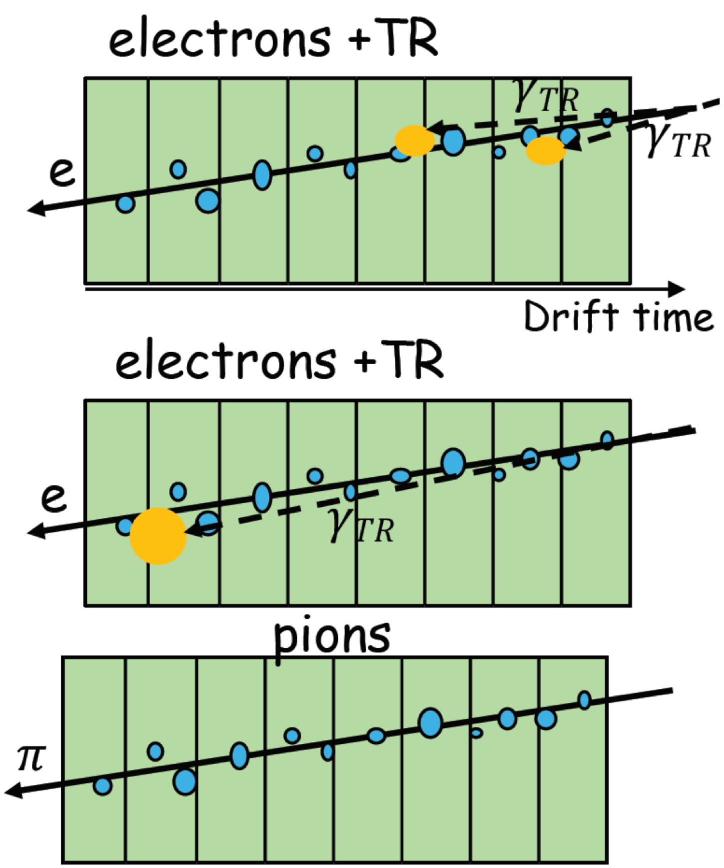
During the previous spring test run we had a problem with powering 3 modules (GEMTRD and 2 standard GEM trackers) with a small NIM crate : after few uncontrolled HV jumps occurred, we were not able to operate GEMTRD module.

The GEMTRD was removed from the testbeam. Test with a cosmics at Uva didn't showed any misbehavior of the module (no optical inspection inside the module)

Moving currently to the full size NIM crate and new HV power -supply CAEN (N1470ET 4 channels 8kV/3mA) was delivered in October



GEANT4: electron and pion comparison



Soft TR-photons:

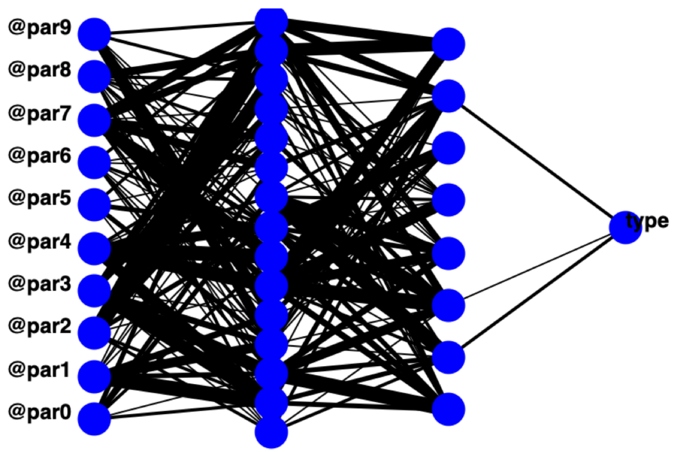
- absorbs near entrance window, therefore have large drift time
- sensitive to dead volumes, like Xe-gap, cathode material.
- Increase of radiator thickness does not lead to increase of number of soft-photons (radiator self-absorption)

Hard TR-photons:

- Depending on energy of TR-photons, could escape detection (depends on detection length)
- Increase of radiator leads to increase of hard TR-spectra.

Separation/ Identification of TR-clusters and dE/dx clusters

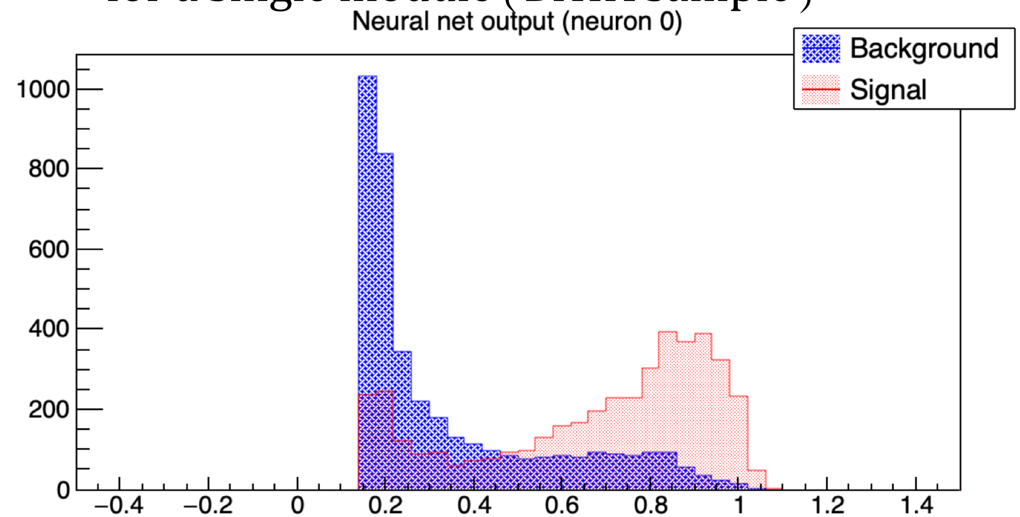
Machine learning technique



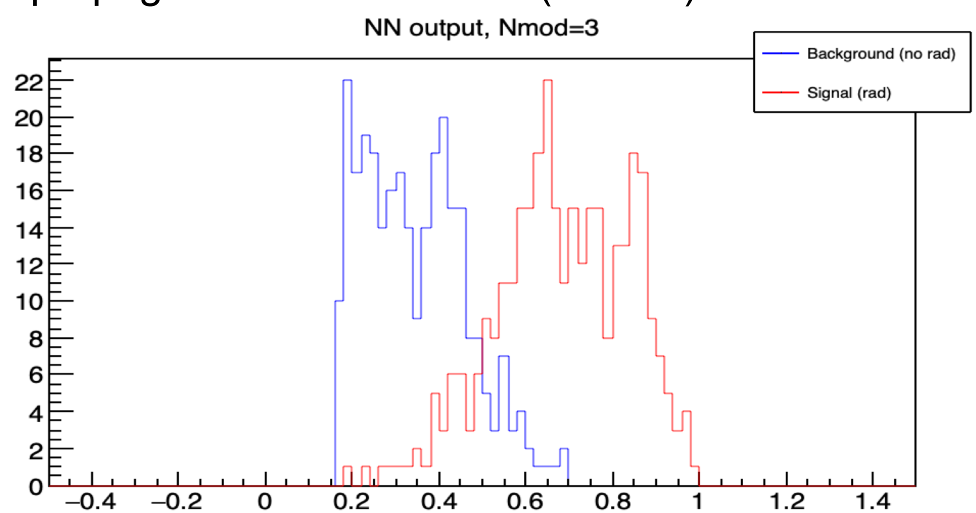
Upto 20 variables were used as input for likelihood and artificial neural network (ANN) programs, such as JETNET or ROOT-based (Multi-layer Perceptron).

We compared cluster search method and integrated charge within a bin (drift slice).

Multilayer perceptron output for a single module (DATA sample)



propagation for 3 modules (bottom) for real data sample



Machine learning technique on FPGA

On-line particle identification:
to move a part of an off-line reconstruction software into on-line (FPGA).
This is a collaborative effort with Hall-D (GlueX) experiment and ODU (engineering department)
Could be applied for single detector as well as for the GLOBAL PID (dE/dx, Cherenkov det, calorimeters, TOF, TRD…)

Step1.
-> Optimize neural network training and optimization of input variables and topology
-> Compare with likelihood method.
-> Optimization of neural network topology for application in FPGA.

Step2. FPGA (VIRTEX) was ordered (expecting delivery by the end of January)

Step3.
-> Implementation of the trained network in FPGA
-> Add streaming readout

Joint GlueX-EIC-PANDA Machine Learning Workshop

25-29 May 2020
GSI
Europe/Berlin timezone

- Overview
- Timetable
- Registration
  - Registration Form
- Participant List
- Timetable compact
- Location: GSI Darmstadt
- Travel Information
- GSI Guesthouse
- Hotels around

Support

r.kliemt@gsi.de

This is an internal workshop of the GlueX, EIC and PANDA collaboration. The aim of the workshop is to improve the know-how of machine learning techniques usable for the two experiments and to improve the collaboration between them.
The workshop aims at beginners and more experienced users/developers. It is organized in a way that there are lectures and tutorials connected to the lectures in the morning and working groups in the afternoon.

Starts May 25, 2020 08:00
Ends May 29, 2020 18:00
Europe/Berlin

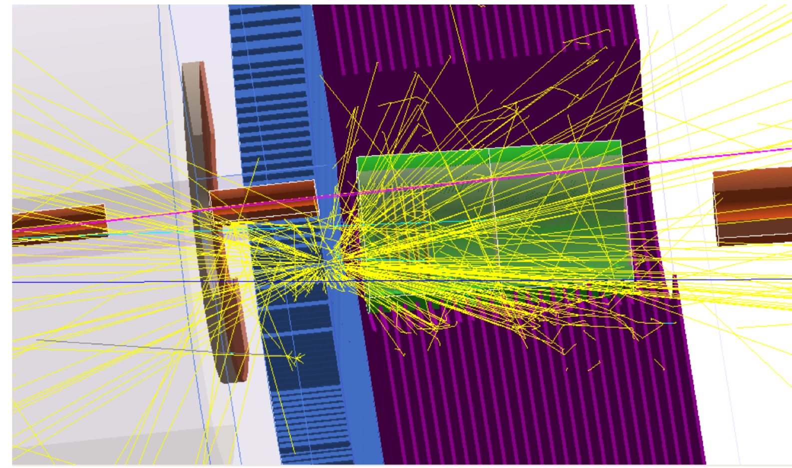
GSI
KBW Auditorium

GSI Helmholtzzentrum für
Schwerionenforschung GmbH
Planckstraße 1
64291 Darmstadt

We will collect a conference fee of 150€ which includes coffee breaks and a dinner.

GEANT4: integration of TRD into a global detector setup (g4e)

GEM-TRD is integrated into “g4e” version of JLEIC detector



Detector description/construction

Configuration structure:

- include
- src
- design
- all
  - cb_CTD
  - cb_DIRC
  - cb_EMCAL
  - cb_HCAL
  - cb_Solenoid
  - cb_VTX
    - cb_VTX.hh
  - ce_EMCAL
  - ce_GEM
  - ce_MRICH
  - ci_DRICH
  - ci_EMCAL
  - ci_GEM
  - ci_HCAL
  - ci_TRD
    - ci_TRD.hh
  - ffe_CPOL
  - ffe_LUMI
  - ffi_ZDC
  - fi_EMCAL
  - fi_TRKD1

```
#include "JLeicDetectorConfig.hh"


struct ci_TRD_Config {
// define here Global volume parameters
    double RIn = 20 * cm;
    double ROut = 200 * cm;
    double ThicknessZ = 40 * cm;
    double PosZ;
    G4double fRadZ;
    //----------------------------
    double fGasGap = 0.600 * mm;    // for ZEUS  300-publication
    double fRadThick = NAN;
    int fFoilNumber = NAN;
    //----------------------------
    double det_RIn = 50 * cm;
    double det_ROut = 100 * cm;
    double det_ThicknessZ = 2.5 * cm;
    double det_PosZ;
    G4double fDetThickness;
    G4double fDetLength;

    double fAbsorberThickness = 0.050 * mm;
    double fAbsorberRadius = 100. * mm;
    double fAbsorberZ = 136. * cm;
    double fDetGap = 0.01 * mm;
    int fModuleNumber = 1;
    G4Material *fRadiatorMat;         // pointer to the mixed TR radiator material
    G4Material *det_Material;

    G4double fRadThickness = 0.020 * mm;    // 16 um // ZEUS NIMA 323 (1992) 135-139, D=20um, dens.= 0.1 g/cm3
```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GEANT4: continue the integration of TRD into a global detector setup (g4e)

TR-radiator and gas absorber are described

```
G4cout << "use for Rad totDensity = " << totDensity / (g / cm3) << " g/cm3 " << G4endl;

G4double fractionFoil = foilDensity * foilGasRatio / totDensity;
G4double fractionGas = gasDensity * (1.0 - foilGasRatio) / totDensity;
G4Material *radiatorMat0 = new G4Material("radiatorMat0", totDensity, 2);
radiatorMat0->AddMaterial(CH2, fractionFoil);
radiatorMat0->AddMaterial(Air, fractionGas);
G4double NewDensity = 0.083 * (g / cm3);
G4Material *radiatorMat = new G4Material("radiatorMat", NewDensity, 1);
radiatorMat->AddMaterial(radiatorMat0, 1.);
G4cout << "new  Rad with totDensity = " << NewDensity / (g / cm3) << " g/cm3 " << G4endl;

G4double XTR_density = radiatorMat->GetDensity();
G4cout << "Read back Rad totDensity = " << XTR_density / (g / cm3) << " g/cm3 " << G4endl;
// default materials of the detector and TR radiator
cfg.fRadiatorMat = radiatorMat;
fFoilMat = CH2; // Kapton; // Mylar ; // Li ; // CH2 ;
fGasMat = Air; // CO2; // He; //
//-------------------------material -------------------------------


cfg.fRadThick = 10. * cm - cfg.fGasGap + cfg.fDetGap;

cfg.fFoilNumber = cfg.fRadThick / (cfg.fRadThickness + cfg.fGasGap);

printf("fFoilNumber1=%d \n", cfg.fFoilNumber);
cfg.fRadZ = -cfg.ThicknessZ / 2 + cfg.fRadThick / 2 + 2 * cm;

foilGasRatio = cfg.fRadThickness / (cfg.fRadThickness + cfg.fGasGap);

fSolidRadiator = new G4Tubs("ci_TRD_Radiator_Solid", 50 * cm, 100 * cm, 0.5 * cfg.fRadThick, 0., 36
fLogicRadiator = new G4LogicalVolume(fSolidRadiator, cfg.fRadiatorMat,
                                     "ci_TRD_Radiator_Logic");

attr_ci_TRD_rad = new G4VisAttributes(G4Color(0.8, 0.7, 0.6, 0.8));
attr_ci_TRD_rad->SetLineWidth(1);
attr_ci_TRD_rad->SetForceSolid(true);
fLogicRadiator->SetVisAttributes(attr_ci_TRD_rad);

fPhysicsRadiator = new G4PVPlacement(0,
                                     G4ThreeVector(0, 0, cfg.fRadZ),
                                     "ci_TRD_Radiator_Phys", fLogicRadiator,
                                     Phys, false, 0);
```

TR process is included into a physics list :

```
void JLeicPhysicsList::ConstructEM()

// G4cout<<"fMinElectronEnergy = "<<fMinElectronEnergy/keV<<" keV"<<G4endl;
// G4cout<<"fMinGammaEnergy = "<<fMinGammaEnergy/keV<<" keV"<<G4endl;
G4cout<<"XTR model = "<<fXTRModel<<G4endl;
std::cout<<"XTR model = "<<fXTRModel<<G4endl;

const G4RegionStore* theRegionStore = G4RegionStore::GetInstance();
G4Region* gas = theRegionStore->GetRegion("XTRdEdxDetector");

G4VXTRenergyLoss* processXTR = 0;

if(fXTRModel == "gammaR" )
{
  // G4GammaXTRadiator*
  processXTR = new G4GammaXTRadiator(pDet->GetLogicalRadiator(),
                     100.,    //--  AlphaPlate 100
                     100.,    //--  AlphaGas   100
                              pDet->GetFoilMaterial(),
                              pDet->GetGasMaterial(),
                              pDet->GetFoilThick(),
                              pDet->GetGasThick(),
                              pDet->GetFoilNumber(),
                              "GammaXTRadiator");
}
else if(fXTRModel == "gammaM" )
{
  // G4XTRGammaRadModel*
  processXTR = new G4XTRGammaRadModel(pDet->GetLogicalRadiator(),
                              100.,
                              100.,
                              pDet->GetFoilMaterial(),
```

```
{
    // Construct processes for electron
    theeminusStepCut = new JLeicStepCut();
    theeminusStepCut->SetMaxStep(MaxChargedStep) ;
    //theeminusStepCut->SetMaxStep(100*um) ;
    G4eIonisation* eioni = new G4eIonisation();
    G4PAIModel*     pai = new G4PAIModel(particle,"PAIModel");
    eioni->AddEmModel(0,pai,pai,gas);

    pmanager->AddProcess(new G4eMultipleScattering,-1,1,1);
    //pmanager->AddProcess(new G4eMultipleScattering,-1,-1,-1);
    pmanager->AddProcess(eioni,-1,2,2);
    pmanager->AddProcess(new G4eBremsstrahlung,-1,3,3);
    pmanager->AddDiscreteProcess(processXTR);
    pmanager->AddDiscreteProcess(new G4SynchrotronRadiation);
    pmanager->AddDiscreteProcess(theeminusStepCut);

}
```

Streaming readout and joint setup

- Participation in the Streaming V meeting
- Working on a readout solutions (cheap and satisfying our needs) . One of the solutions is a modified version of our current DAQ setup with FlashADCs125. Ongoing…. (planning to assemble one module (10x10cm, 500 channels) in summer 2020.
- Planning to perform a joint test with eRD1 (CAL) and mRICH (eRD6) prototypes during this spring run.

To Do this year:

1) Perform gas-HV scan and to find an optimal mixture and HV settings for TRD operation.

2) Test of new Radiators: Use the current setup to validate a performance of new TRD radiators.

3) Streaming readout for GEM-TRD operation – ongoing

Our project has been recognized and supported by Hall-D JLAB.
We got additional support for development of readout chain, including an implementation of Machine Learning on FPGA for online data processing and data reduction. Planning to perform first test in FY20.

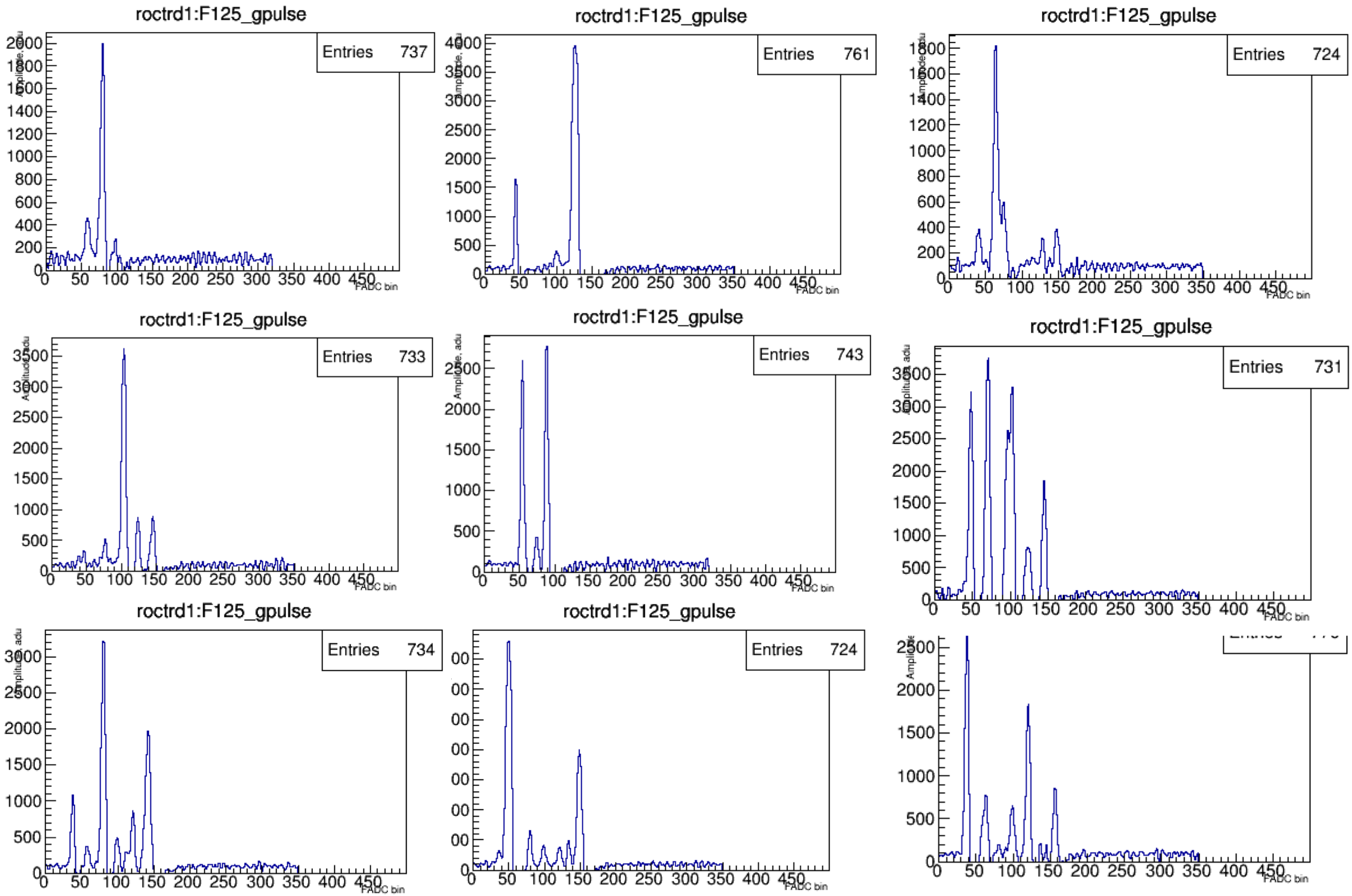
Summary

- Electron identification is very important for EIC physics. Due to a large hadron background expected in the forward (Hadron-endcap) region, a high granularity tracker combined with TRD functionality could provide additional electron identification - GEM-TRD/T
- GEANT4 simulation of GEM-TRD has been performed
- We need a pion beam to complete our measurements (at Fermila or SPS CERN) . Planning in FY2021-2022 (with additional support from EIC R&D)
- Looking forward to a collaboration with other eRD consortiums !

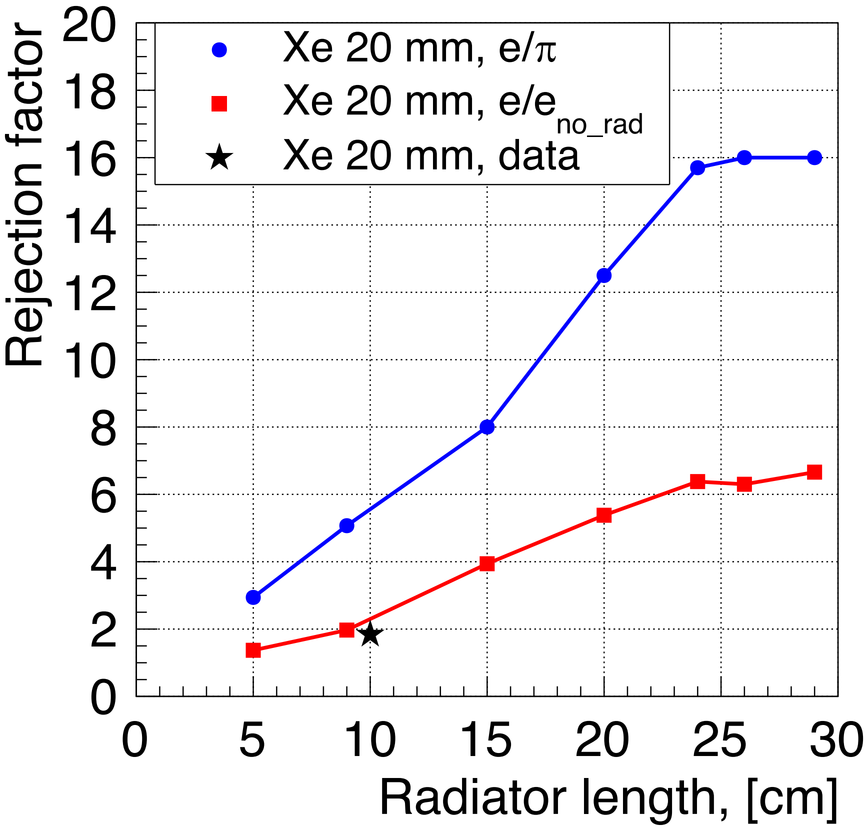
Thank you!

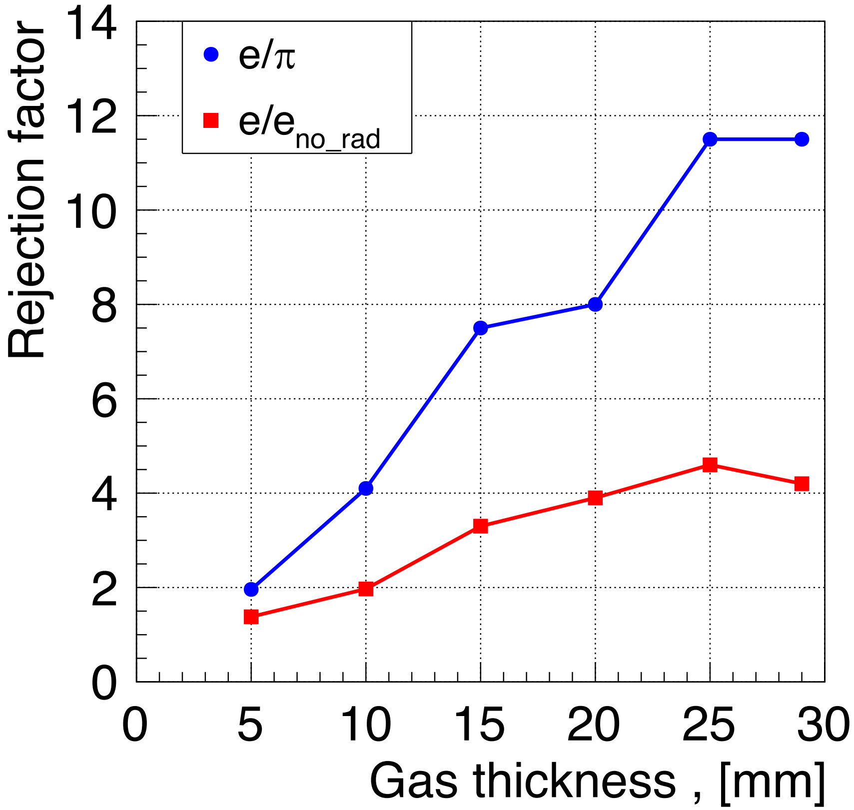
Backup

Signals from GEMTRD using FlashADC125



e/π rejection

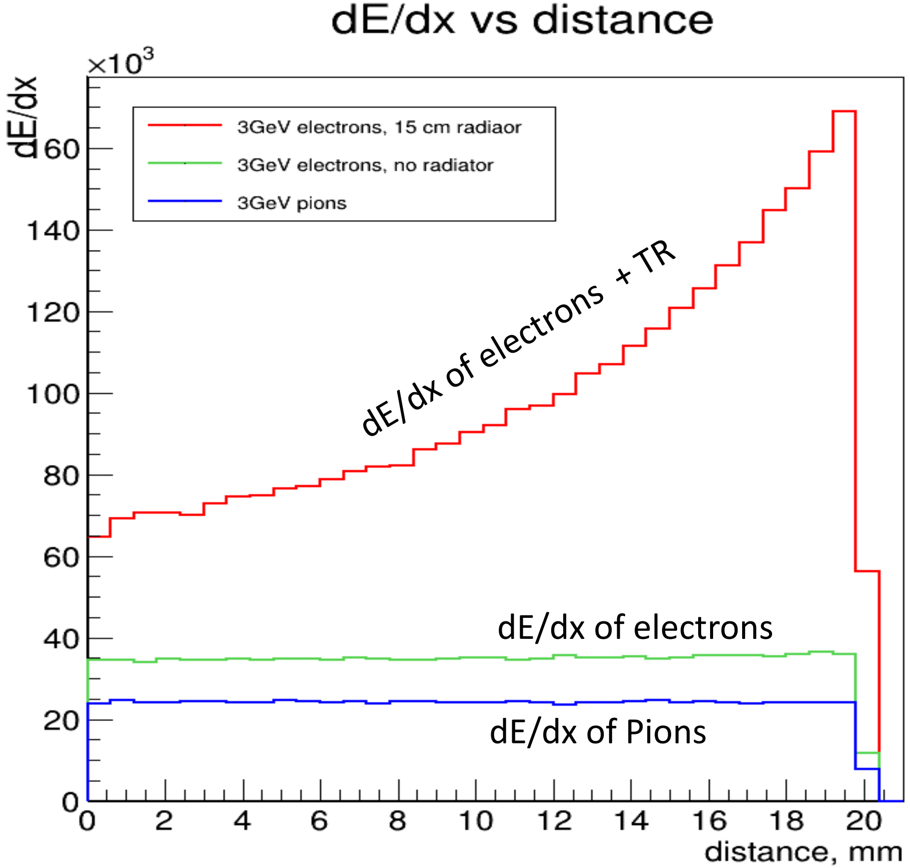




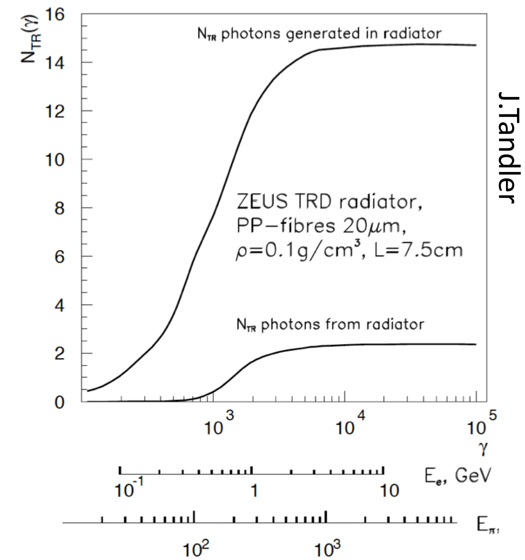
Tacking into account a limited space between dRICH and EMCAL, a single module of ~15-16 could be achieved with a single module (20cm radiator and 2.5cm gas).

GEANT4: electron and pion comparison

Energy deposition (dE/dx + TR) vs distance



e,π ~3 GeV



Pions does not produce TR photons up to energy ~ 100 GeV

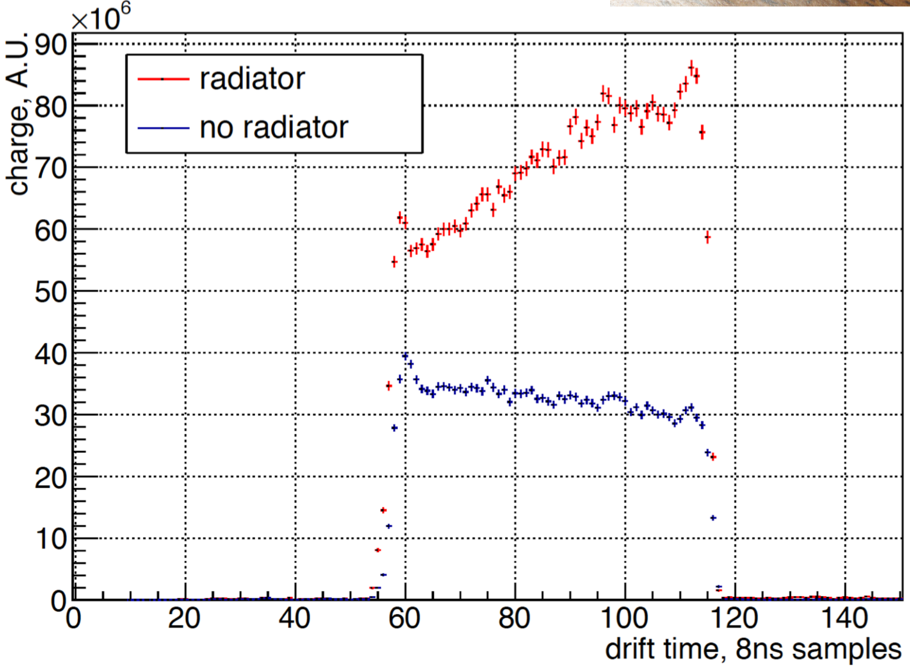
One could estimate TRD performance with just e-beam, by comparing regions with and without radiator.
Note, that due to lower <dE/dx>, e/π rejection performance will be better.

Charge as a function of drift distance

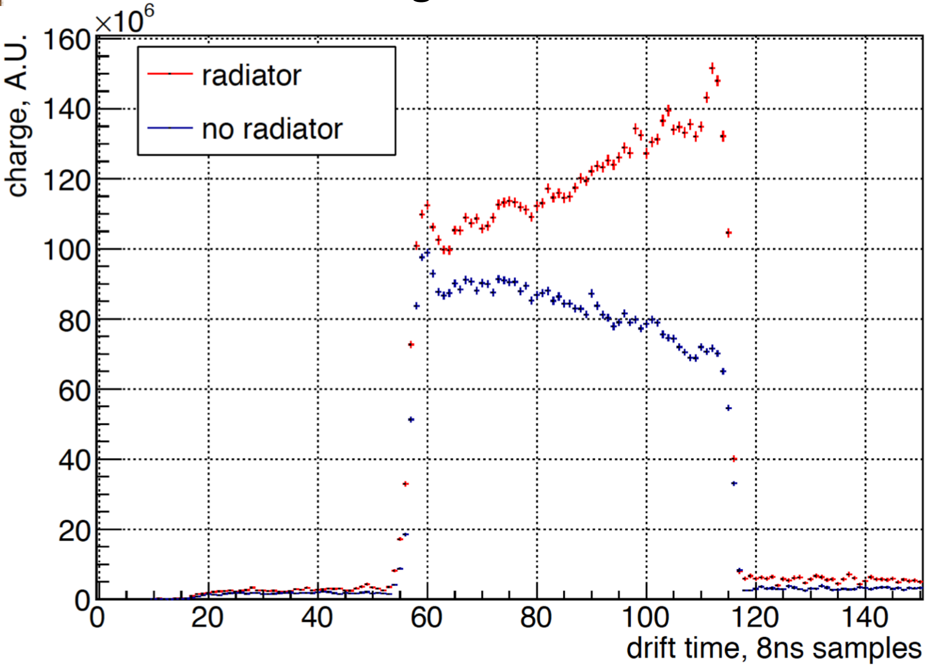
Fleece radiator:
Random oriented in 2D
Polypropylene fibers ($20\mu m$)

Regular foils:
~200 polypropylene foils (~13 μm thick) with spacers (~180μm) made from nylon net

Fleece



Regular foils

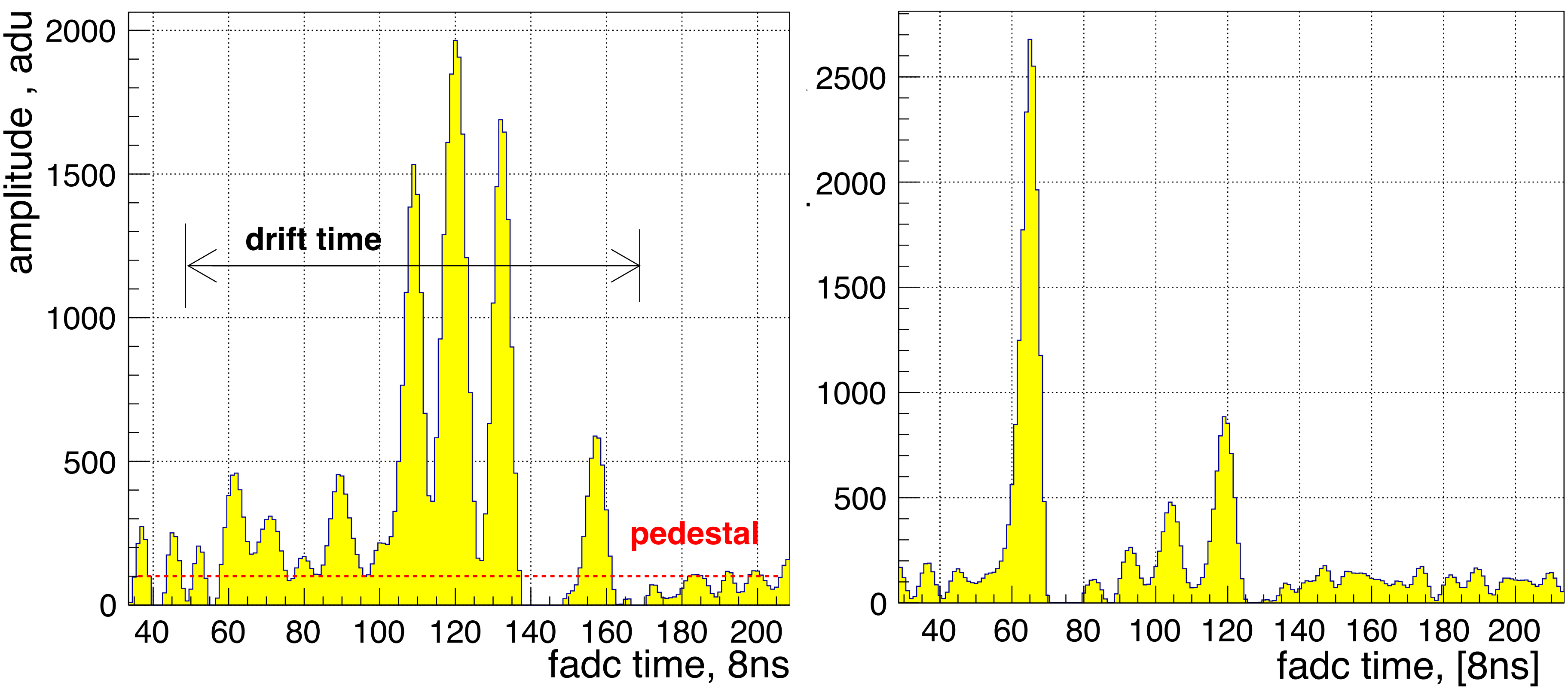


Yulia Furletova

Readout electronics

- ✓ FlashADC 125MHz setup shows excellent performance!
- ✓ Pre-amplefiers : undershooting, no base-line restorer !!!

- ✓ Collaboration with eRD23 (streaming readout) to find the best solution for GEM-TRD operation in a streaming mode



Backup